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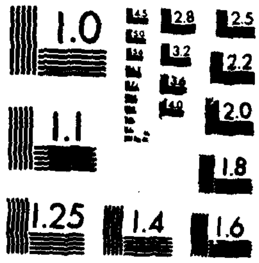

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This report summarises investigations into phonon scattering mechanisms at surfaces. Fast heat pulse measurements have shown that the strecthing of heat pulses, in transit between a generator and detector, occurs in a damaged region below the heater film. The scattering responsible is most probably due to strain fields put into the material by the action of mechanically polishing the surface. The observed propagation, in which high energy phonons exhibit diffusive propagation whilst the low energy phonons are ballistic, is one manifestation of quasi-diffusion. This type of propagation will play an important role in the study of superlattice systems by phonon techniques.

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ELECTRON-PHONON INTERACTION IN GaAs/AlGaAs STRUCTURES

Third and Final Report

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PRINCIPAL INVESTIGATOR: M N WYBOURNE

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ELECTRON-PHONON INTERACTION IN GaAs/AlGaAs STRUCTURES

During the reporting period, the major advance in this programme was the elucidation of the phonon scattering mechanism at surfaces. These results will be of considerable significance when phonon scattering data from semiconductor interfaces or boundaries are analysed. Unfortunately, during this reporting period no further attempts were made to grow the AlGaAs/GaAs cross-structures, in which to study electron-phonon scattering.

In order to study phonon scattering at surfaces, phonon pulses were injected into a highly perfect sapphire substrate by Joule heating a thin metallic film (~10 nm) that was thermally deposited onto the surface. Two materials were used to form the heater films, nichrome ($Ni_{50}Cr_{50}$) and gold-palladium ($Au_{60}Pd_{40}$), and these were excited electrically with pulses of up to 40V in magnitude and of between 2.0 and 0.8 ns in duration. The heat pulses thus generated propagated along the (2243) axis and were detected by a superconducting bolometer ($Pb_{80}Bi_{20}$) on the opposite substrate surface to the heater films. Two unexpected features of the detected signals were observed: firstly, the amplitude of the detected pulse scaled with the excitation pulse energy and not the power and, secondly, the detected pulse was considerably broader than the excitation pulse. These features have not been observed previously in conventional heat pulse experiments in which the excitation pulse widths are generally 50 ns or greater.

We studied several heater films and found that the detected signal amplitude, the pulse stretching factor and the ratio of the detected longitudinal and transverse signal amplitudes were all dependent on the thickness and the type of material used to fabricate a particular heater film. If pulse stretching was occurring by the process of phonon trapping within the heater film itself, the pulse length would scale as the square of the film thickness. This was not observed for either the nichrome or the gold-palladium films. Furthermore, the strength of the phonon scattering required to trap the phonons within the film for a time sufficient to explain the broadened pulse is unrealistically large. We postulate, therefore, that the pulse stretching occurs in a subterraneous layer beneath the heater film. High energy phonons emitted from the heater enter this layer where they undergo diffusive propagation, the scattering process responsible for the diffusive propagation being frequency dependent. By the action of three phonon processes, the dominant frequency of the injected phonon flux is down-graded until the scattering of the lower energy phonon is insufficient to maintain diffusive propagation. Low energy phonons, therefore, 'leak' out of the subterraneous layer and experience ballistic propagation across the bulk of the substrate to the surface opposite the heater where they are detected. Modelling the observed pulse length as a function of excitation power, we can fit the data with a phonon diffusion length, within the subsurface layer, having a linear frequency dependence. This frequency dependence is consistent with phonon scattering from strain fields and we estimate that the strain field extends ~20 μm below the surface. This is perfectly reasonable for a mechanically cut and polished surface.

This model is also able to explain the fact that the heat pulses generated by the nichrome films were stretched to a greater extent than those from the gold-palladium films. Using the Stefan-Boltzmann law, together with the ratio of the phonon escape time from the film to the excitation pulse length, it is possible to estimate the lattice temperature of the heater films. Combining this with the phonon spectrum for the particular material, we have estimated the energy of the dominant phonons being injected into the substrate and have shown that the dominant phonons emitted from the gold-palladium were of considerably lower energy than those emitted from the nichrome. Taking into account the frequency dependence of the diffusive scattering, this explains why the observed pulse stretching associated with the gold-palladium films was less than that of the nichrome films.

Another significant difference between the two heater materials was found: at the maximum excitation energy density (~ 1.5 J mm^{-2}) the gold-palladium was emitting predominantly zone-boundary phonons while the nichrome was emitting 0.75 zone-boundary phonons. As the excitation energy density was lowered, the dominant phonon energy emitted from the nichrome film fell commensurately with the value of the excitation attenuation. However, the gold-palladium film maintained its emission of predominantly zone-boundary phonons until the level of excitation had dropped by ~20 dB. These differences between the phonon emission from the two heater materials enable us to explain the observed differences in the detected pulse magnitudes and phonon mode ratios as a function of the excitation power.

Computer simulations have verified the model predictions made in these experiments.

In conclusion, fast heat pulse measurements have shown that the stretching of heat pulses, in transit between a generator and detector, occurs in a damaged region below the heater film. The scattering responsible is most probably due to strain fields put into the material by the action of mechanically polishing the surface. The observed propagation, in which high energy phonons exhibit diffusive propagation whilst the low energy phonons are ballistic, is one manifestation of quasi-diffusion. This type of propagation will play an important role in the study of superlattice systems by phonon techniques.

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